AMERICAN BUREAU OF' SHIPPING

"EXTENSION OF E7024 ELECTRODE APPLICATIONS IN SHIPBUILDING"

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FOREWORD

This investigation presents the results of a research and development program which was initiated by the Ship Production Committee of the Society of Naval Architects and Marine Engineers and financed through a cost sharing contract between the U. S. Maritime Administration, Bethlehem Steel Corporation and the American Bureau of Shipping. The program objective was to explore the feasibility or extending the use of E7024 type electrodes in shipbuilding.

Mr. W. C. Brayton, Bethlehem Steel Corporation was the Program Manager. The program was carried out by the American Bureau of.Shipping under the direction of Mr. B. L. Alia, Mr. I. L. Stern was the Project Manager and Messrs. C. R. Herbst and D. Y. Ku served as Project Engineers.

In addition, the services of Sun Shipbuilding and Dry Dock Company in preparing butt welds are acknowledged.

Special acknowledgement is made to the members of Welding Panel SP-7 of the SNAME Ship Production Committee who served as technical. advisers.

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EXECUTIVE SUMMARY

BACKGROUND

Use of AWS E7024 type electrodes in shipbuilding is generally limited to single pass fillet welding for ABS Grade 1 application (up to 1/2 inch thick Grade A steel) in the flat and horizontal welding positions for attachment of stiffening members. In the case of barges for river, bay and sound service the E7024 electrodes may also be used for single pass lap joints. These limitations are associated with the absence of an impact requirement and the lower (17%) elongation requirement of the governing AWS Specification for E7024 type electrodes. Requirements of the AWS electrode grades approved for ABS Grade 2 or 2Y applications include impact requirements and provide for higher elongation requirements.

Several brands of E7024 electrodes have been qualified as ABS Grade 2 or 2Y electrodes under the ABS specification for filler metals, and as such have been approved for butt and fillet welding all thicknesses of ABS Grade A, B, DS, AH, and DH steels. The cost of manual metallic arc fillet welding could be reduced if a class of E7024 electrode could be made available for Grade 2 or 2Y fillet and/or butt weld applications; fillet applications reflect a significant amount of shipyard welding.

OBJECTIVE

The primary objective of the project is to determine the extent to which use of AWS type E7024 electrodes can be broadened in regard to fillet welding applications, with particular emphasis on single pass fillet welding.

The second objective is to determine the extent to which use of AWS E7024 type electrodes can be broadened in regard to unlimited use for fillet and butt welding in Grades A, B, D, DS, AH, and DH steels.'

ACHIEVEMENT

Based on test results several brands of AWS E7024 electrodes exhibited properties that are equal to AWS E6011, E7028, or ABS Grades 2, 2Y electrodes. A class of E7024 electrodes meeting elongation and Charpy V-notch requirements equivalent to ABS Grades 2 and 2Y could be a realistic consideration in the AWS A5.l Specification. A recommendation is being made to AWS that action be initiated to establish additional classes of E7024 and E6024 type electrodes with specified elongation and impact properties which would extend their applicability to shipbuilding and other industries,

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1.0 BACKGROUND

The AWS A5.1-78 specification indicates that "The E7024 electrodes are well suited for making fillet welds. The welds are slightly convex to flat in profile, with a very smooth surface and an extremely fine ripple. These electrodes are characterized by a smooth, quiet arc, very low spatter, and low penetration. They can be used with high travel speed."

Application for E7024 electrodes in shipbuilding is guided by the provision in the ABS Publication of A proved Welding Electrodes which indicates the following: “Electrode classification E7024 may be used for Grade 1 single pass fillet applications in the fiat and horizontal welding positions for attachment of stiffening members. (Grade 1 applications involved we1ding where one of the members being joined is ordinary strength ABS Grade A steel up to 1/2” in thickness). In the case of barges for river, bay and sound service the E7024 electrodes may also be used for single pass lap joints.” ‘Acceptability of E7024 electrodes in both cases is contingent on procedure tests being conducted at the shipyard for the particular brand of electrode to demonstrate that adequate penetration and elongation is achieved. Macro-etch and longitudinal fillet weld guided bend tests are required for each size electrode to be used in production. Welding current should be controlled and pericdic production tests should be carried out to insure that adequate weld quality is maintained.

The ABS limitations on E7024 electrodes are associated with the absence of a Charpy impact requirement and the lower (17%) elongation requirements of the governing AWS specification as compared to the higher elongation requirements for the electrodes used for ABS Grade 2 and 3 (for ordinary strength steels) and 2Y and 3Y (for higher strength steels) applications (22% and 20% respectively).

Requirements for ABS grades of ordinary and higher strength electrodes and AWS specifications for E7024, E7028, and E6011 electrodes are shown in Table 1. The applicability of these electrode grades to the various grades of ABS steels are shown in Table 2. Several brands of E7024 electrodes have been qualified as ABS Grade 2 or 2Y electrodes and as such have been approved for butt and fillet welding all thicknesses of ABS Grades A, B, DS, AH, and DH steels respectively.

Preliminary information indicates that opportunities exist to effect significant economies if class of E7024 electrode could be available which could be used in Grade 2 or 2Y fillet and/or butt weld applications; such fillet applications reflect a significant amount of shipyard welding.

The E7024 type electrode is an iron-powder type having a relatively low specified minimum elongation requirement, i.e. 17% minimum in 2 inches, as compared to 22% minimum for some other E60XX and 70XX electrodes. In addition, it exhibits comparatively low penetration properties. These electrodes are not generally recommended for multipass welding. However, there are valid reasons for their use and fabricators prefer them over other types of electrodes because of their versatility, case of handling, good fillet weld profile and appearance, as well as high deposition rate potential.

2.0 OBJECTIVE

The objective of this project was to explore the feasibility of substituting or extending the use in shipbuilding of “E7024 Type” electrodes in the following areas:

1. Determine the extent to which use of AWS E7024 electrodes can be broadened in regard to fillet welding applications, with particular emphasis on single pass fillet welds.
2. Determine the extent to which use of AWS E7024 electrodes can be broadened in regard to unlimited use for butt and fillet welding in Grades A, B, D, DS, AH, and DH steels.

3.0 APPROACH

The overall approach was to determine the weld soundness and range of mechanical properties (including elongation and toughness) available from commercially available AWS E7024 electrodes and conduct comparative tests on AWS brands which were ABS approved for Grade 2 and 2Y applications respectively.

Additional information relative to E7024 electrodes was obtained from in-house data which had formed the basis of approval for the various brands of E7024 electrodes included in the current ABS listing of approved filler metals.

4.0 BASE METALS

The materials used for butt and fillet welds was ABS Grade B semi-killed steel in 1/2" and 1" thicknesses; chemical and mechanical properties are shown in Table 3. Seven (7) different brands of 1/4" AWS E7024 electrodes were included in the test program. One brand each of E6011 and E7028 (equivalent to ABS Grades 2 and 2Y respectively)were also included. E601 was chosen since, like the E7024, it is an AC-DC approved electrode. E7028 was selected to represent an iron powder coated Grade 2Y electrode. Table 4 indicates the ABS filler metal grades, and corresponding AWS classifications.

5.0 WELDMENT PREPARATION

Butt welds were made in accordance with the AWS A5. 1-78 specification by shipyard welders. Fillet welds were made in the ABS laboratory using the unusually slow travel speeds necessary to produce the required fillet size suitable for the scheduled tensile and impact tests. Data relative to tensile and impact properties of fillet welds, which are not provided for in electrode specifications, were intended to provide some preliminary data relative to such properties.

5.1 Butt Welds

Multipass butt welds were prepared in accordance with the provisions of AWS A5.1-78 for all weld metal tests; and they were inspected by ultra-sonics and radiography at a shipyard in accordance with the ABS Rules for Nondestructive Inspection of Hull Welds. Figure 1 indicates the specific joint design used and specimens selected. Welding parameters are shown in Table 5.

5.2 Fillet Welds

Single pass fillet welds were made with each brand of E7024 electrodes; 1/2" base plate was used for tension tests; 1" plate was used for Charpy tests to provide sufficient specimen length. To obtain the desired fillet sizes, a two pass technique was used with the E6011 and E7028 electrodes for the CVN test assemblies, For all fillet welds a lower than normal travel speed was used to obtain sufficient fillet sizes for the scheduled mechanical tests. Welding parameters and details are shown in Tables 6 and 7.

6.0 TEST PROCEDURE

6.1 Visual Examination

All welds were examined at 10X and 70X to evaluate soundness.

6.2 Mechanical Testing of Welds

The following mechanical tests were conducted for each brand of electrode: (See Figs. 1 and 2)

All weld metal tensile tests - butt and fillet welds*

Charpy V-notch impact tests - butt and fillet welds*

Guided bend tests (root, face and side) - butt welds

*Subsize specimens were used for the fillet weld tests.

7.0 TEST RESULTS

7.1 Soundness Evaluation of Welds

7.1.1 Butt Welds - Nondestructive Tests (conducted at shipyard)

In general all welds were within Class A radiographic and ultrasonic acceptance limits of the ABS Rules for Nondestructive Inspection of Hull Welds, except for the E6011 brand Cl and the E7024 brand K4 which had significant ultrasonic indications to the extent shown in Fig. 5. Radiographs of the K4 weld were acceptable; radiographs of the Cl weld showed unacceptable lack of fusion.

7.1.2 Fillet Welds - Macroexamination

No significant defects were found on examination of sections at 1OX and 70X. Typical sections are shown in Figs. 6a and 6b,

7.2 Butt Welds - Mechanical Tests

The results of mechanical tests are shown in Table 8. Tensile, yield, and elongation and CVN results are shown graphically in Figs. 3a, 3b and 4. Porosity notation in Fig. 3b and Table 8 refers to indications of very fine porosity in structure surface.

7.2 Butt Welds - Mechanical Tests (continued)

The Bureau has accumulated substantial data on E7024 electrodes from deposited metal tests conducted in connection with electrode qualification testing and annual check testing to meet the requirements for listing in the ABS publication of Approved Filler Metals. Table 10 indicates the electrodes of the E7024 type with mechanical properties and chemical compositions that have met the ABS requirements for listing as Grade 2 or 2Y as well as those approved as ABS Grade 1 or as AWS E7024.

7.3 Fillet Welds

The results of tensile and Charpy tests of each brand are shown in Table 9.

8.0 ANALYSIS OF RESULTS

8.1 Mechanical Properties of Butt Welds

Table 8 and Figs. 3a and 3b indicate that the tensile and yield strengths, elongation and CVN test results for several brands of E7024 electrodes tested meet requirements for ABS Grades 2 or 2Y. The low elongation exhibited by brands C4, K4, and L4 was associated with porosity in one or both of the tensile test samples. As indicated in Table 8 and Fig. 4 all E7024 brands exhibited CVN properties which meet the Charpy V-notch requirements for Grades 2 and 2Y electrodes; four of these brands met or exceeded the requirements for ABS Grade 2 or 2Y electrode in respect to tensile, yield, elongation and Charpy test results.

8.2 Evaluation of Related In-House Test Data

In-house data on a total of 60 tests on 18 brands of E7024 type electrodes is shown in Table 10, and illustrated graphically in Figs. 7 through 10. The data was obtained in connection with submissions for ABS approved

8.2 Evaluation of Related In-House Test Data (continued)

filler metals. As inciated therein all tensile and yield strength values meet higher strength requirements for the ABS filler metal grades. Elongation is 22% or higher for 53 of the 60 results. 32 of 34 Charpy impact test results met or exceeded 35 ft-lbs at O°C (the ABS Grade 2 Charpy requirement) and 30 of the 34 results for which data is available met a value of 40 ft-lbs at O°C (the ABS Grade 2Y requirement).

8.3 Evaluation of Fillet Welds

There are no specific requirements for conducting all weld metal tests of fillet welds. Test results which are shown in Table 9 are presented for reference and general information. The Charpy V-notch values for the E7024 fillets are lower than that of the corresponding E6011 and E7028 welds,and the E7024 butt welds. However, the E7024 fillet welds were made with a single pass, whereas the other fillets as well as all butt welds were multipass. The scope of the project did not permit resolution of the question as to whether the differences observed were primarily related to the fact that the E7024 fillets were large single pass welds. Single, pass fillets made with E6011 and E7028 electrodes were insufficient in size for selections of tensile and Charpy impact specimens.

9.0 DISCUSSION

The test results indicate that there are variations of mechanical properties in the group of E7024 electrodes. A number of brands exhibited properties that were equal to or better than the specifications, requirements for AWS E6011, E7028 or ABS Grade 2 and 2Y electrodes. The present restriction on E7024 electrodes is based on the relatively low specified elongation (17%) in the AWS specification, which is less than the 22% of ABS Grade 2 and the 20% of ABS Grade 2Y, and the fact that no CVN requirements are

9.0 DISCUSSION (continued)

electrodes meeting a 22% or 20% minimum elongation requirement for Grade 2 or 2Y and a Charpy V-notch value equivalent to ABS Grade 2 or 2Y could be a realistic consideration for incorporation into an AWS A5.1 specification. The availability of such classes would enable shipbuilding and other industries to use E7024 electrodes for applications where a 22% or 20% minimum specified elongation and adequate (PJN properties are required. The relatively high deposition rates and usability of E7024 electrodes could reduce cost. The desirable contour and smooth surface associated with fillet welds from this type of electrodes may possibly provide improvements in fatigue properties. Evaluation of the degree of fatigue improvement would require further investigation.

Since it is believed that the greatest application for the subject electrode is the welding of ordinary strength steels with-tensile and yiel d strengths of comparable properties, a “E6024” type electrode (modified E7024) should be considered. The lower strength might provide an opportunity to achieve higher elongation and Charpy V-notch properties.

10.0 CONCLUSION

Several brands of E7024 electrodes have the potential of meeting the following requirements:

AWS Specification	Tensile Strength Min. (ksi)	Yield Strength Min. (ksi)	Elong. in 2 in. Min.(%)	CVN Require. Min. (ft-lb @ O°F)
E6024 (proposed)	62	50	22	20
E7024 (proposed modification)	72	60	20	20

As discussed in Section 9.0,E6024 and E7024 type electrodes meeting the above requirements, which are equivalent to ABS Grades 2 and 2Y respectively, would be useful in shipbuilding and other industries.

11.0 RECOMMENDATIONS

11:1 It is recommended that action be initiated to establish the specified E6024 and E7024 types noted above within the AWS A5.1 specification.

11.2 Consideration should be given to carrying out studies of fatigue properties of the fillet welds made with E7024 electrodes to explore any potential fatigue benefits which might be achieved from the more favorable contour.

12.0 FUTURE ACTION

ABS has requested the AWS Committee on Filler Metals to consider the establishment of modified E7024 electrodes as indicated in ABS letter to AWS (see Enclosure 1). Broad application of these electrodes to shipbuilding will be dependent upon the establishment of the proposed AWS electrode classifications and the ability and support of industry to provide electrodes which meet the proposed requirements.

To characterize E7024 welds deposition, additional work has been contracted to explore the relationship between microstructure and mechanical properties of E7024 type welds. The work will be completed in 1981 and the results will be forwarded at that time.

ENCLOSURE 1

American Bureau of Shipping
Sixty-five Broadway
New York, N.Y. 10006

Ref. to: DK/t
Att. Ref.: ML 4-1

22 September 1980

AWS Conmittee on Filler Metal
American Welding Society
2501 Northwest 7th Street
Miami, FL 33125

Attention: Mr. George Hallstrom, Jr., Secretary

Subject: Recommendation of Modification of AWS E7024 Electrode Classification

Gentlemen:

In accordance with the results of the enclosed draft of research project Extension of E7024 Applications in Shipbuilding" I wish to recommend that considerations be given to modification of the AWS A5.1-78, E7024 electrode specification to provide for the proposed E7024 and E6024 types indicated in Section 10.0 of the enclcsed draft.

The provision of an electrode combining the usability of a E7024 type with the inticated toughness and higher elongation could be beneficial to ship-building and other industries.

Your early action on this recommendation would be appreciated.

Yery truly yours,

Bruno L. Alia
Member
A5 Committee on Filler Metals

cc: Chairman A5 Filler Metal-w/p

TABLE 1 - Mechanical Property Requirements for ABS and AWS Filler Metal Grades

Grade	ABS Ordinary Strength Grade			ABS Higher Strength Grade		AWS		
	1	2	3	1Y	2Y	6011(2)	7024	7028(3)
Tensile Strength kg/mm^2 (ksi)	41-57 (58-81)	41-57 (58-81)	41-57 (58-81)	50-67 (71-95)	50-67 (71-95)	43 min. (62) min.	50 min. (72) min.	50 min. (72) min.
Yield Strength (min) kg/mm^2 (ksi)	31 (44)	31 (44)	31 (44)	38 (54)	38 (54)	35 (50)	42 (60)	42 (60)
Elongation (%) 50 mm (2 in.) min.	22	22	22	20	20	22	17	22
CVN (1) ft-lbs	35 @ 68°F	35 @ 32°F	45 @ 14°F	20 @ 32°F	40 @ 32°F	20 @-20°F	Not Required	20 @ 0°F

(1) CVN impact values of ABS grades are for manual and semi-automatic processes.

(2) Acceptable as ABS Grade 3.

(3) Acceptable as ABS Grade 2 and 2Y.

TABLE 2 - Application of Filler Metals to ABS Steel

ABS Hull Structural Steel	Acceptable ABS Filler Metal Grade
Ordinary Strength	
A to 12.5 mm (1/2 in.) inclusive	1, 2, 3
A over 12.5mm (1/2 in.] B, D, DS	2, 3
DN, CS, E	3
Higher Strength	
AH to 12.5 mm (1/2 in.) inclusive	IY, 2Y, 3Y
AH over 12.5mm (1/2 in.), DH	2Y, 3Y
EH	3Y

TABLE 3 - Chemical Composition and Mechanical Properties of ABS Grade B Base Metal.

Chemical Compositions (%)					Mechanical. Properties			
C	Mn	Si	P	S	T. S. kg/mm²(ksi)	Y.S. kg/mm²(ksi)	El. (%) 50mm(2 in.)	Reduction in Area(%)
0.19	***0.73***	0.04	0.012.	0.032	43.9 (62.2)	24.8 (35.1)	*35*	

TABLE 4 - Manual Electrodes

ABS Filler Metal Grade	Acceptable AWS Classification
Ordinary Strength	
1	AWS A5.1-78 E6010, E6011, E6027, E7015, E7016, E7018, E7028, E7048
2	AWS A5.I-78 E6010, E6011, E6027, E7015, E7016, E7018, E7028, E7048
3	AWS A5.1-78 E6010, E6011, E6027, E7015, E7016, E7018, E7048
Higher Strength	
1Y.	AWS A5.1-78 E7015, E7016, E7018, E7028, E7048
	AWS A5.5-69 E8016-C3, E8018-C3
2Y	AWS A5.1-78 E7015, E7016, E7018, E7028, E7048
	AWS A5.5-69 E8016-C3, E8018-C3
3Y	AWS A5.5-69 E8016-C3, E8018-c3

TABLE 5 - Welding Parameters for Butt Welds (Electrode Size 1/4")
Preheat Temp. 225 ± 25°F Max. Interpass Temp. 350°F

Code	Electrode	Pass No.	Volts	Amps
C1	E6011	1	26	245
		2-11	28	240
L8	E7028	1-8	29	390
		9-10	25	350
C4	E7024	1-9	31	390
		10-11	26	340
H4	E7024	1-8	28	335
		9-10	29	290
K4	E7024	1-9	28	375
		10-11	26	345
L4	E7024	1-8	28	390
		9-10	23	340
M4	E7024	1-8	30	385
		9-10	30	360
R4	E7024	1-9	25	400
		10-12	22	350
W4	E7024	1-7	29	380
		8-9	27	330

TABLE 6 - Welding Details for Fillet Welds 1" Plate

Rod Code	Weld	Volts	Amps	Time	Length of	Travel	Approx. Heat Input KJ
C1	1A	32	260	154	10	3.9	128
	1B	32	280	140	10	4.3	126
	1C	30	280	155	10	3.9	130
C1	2A	30	270	117	9-1/2	4.9	100
	2B	32	280	162	9-1/2	3.5	153
	2C	32	280	120	9-1/2	4.8	113
L8	1	34	400	135	9	4.0	204
	2	33	400	83	7	5.1	157
C4	1	38	390	73	7	5.8	155
	2	38	390	72	7-3/4	6.5	138
H4	1	39	380	90	8	5.3	167
	2	38	390	95	8-1/2	5.4	166
K4	1	34	400	87	8	5.5	148
	2	34	400	71	7-1/2	6.3	129
L4	1	31	400	96	8	5.0	149
	2	31	390	89	8	5.4	135
M4	1	33	400	103	8-3/4	5.1	156
	2	35	390	71	7	5.9	139
R4	1	30	400	104	8-1/2	4.1	175
	2	29	420	106	8-1/4	4.7	157
W4	1	37	390	108	8	4.4	195
	2	36	390	74	7-1/2	6.1	139

TABLE 7 - Welding Details for Fillet Welds 1/2" Plate

Rod Code	Weld	Volts	Amps	Time (Sec.)	Length of Weld (in.)	Travel Speed (in./min.)	Approx. Heat Input (KJ/in.)
C1	1A	30	220	110	6-1/2	3.6	111
	1B	28	240	105	6-1/2	3.7	109
	1C	30	240	105	6-1/2	3.7	115
C1	2A	30	240	100	6-1/2	3.9	111
	2B	28	240	100	6-1/2	3.9	103
	2C	28	240	110	6-1/2	3.6	113
L8	1	34	400	80	7	5.3	155
	2	32	400	80	6	4.5	171
C4	1	35	360	70	6	5.1	147
	2	36	360	75	6	4.8	162
H4	1	40	400	70	6	5.1	187
	2	40	380	70	6-1/2	5.6	164
K4	1	34	400	80	6	4.5	181
	2	38	380	70	6	5.1	169
L4	1	34	400	75	6	4.8	170
	2	32	400	77	6	4.7	163
M4	1	34	400	70	6	5.1	159
	2	34	390	70	6-1/2	5.6	143
R4	1	34	400	80	6-1/2	4.9	167
	2	32	400	80	6-1/2	4.9	157
W4	1	34	400	73	6-1/2	5.6	147
	2	34	380	70	6	5.2	151

TABLE 8 - Results of Tests on Butt Welds 1" Plate

Code	C1	L8	C4	H4	K4	L4	M4	R4	W4
Electrode	E6011	E7028	E7024	E7024	E7024	E7024	E7024	E7024	E7024
Tensile Strength (psi)	71,500 71,500	75,500 --	82,300 81,500	77,500 80,200	76,000 75,500	76,400 77,600	73,900 73,000	76,700 77,300	71,600 70,000
Yield Point (psi)	63,000 61,500	67,300 --	74,200 72,100	71,500 72,500	67,800 64,900	69,200 68,500	67,300 65,700	69,500 69,400	62,200 56,500
Elongation % (in 2")	20.0* 23.0*	28.0 --	16.0* 21.0	26.0 20.0	14.0* 18.0*	17.0* 18.0*	18.0* 25.0	21.0* 24.0	25.0 25.0
Reduction of Area (%)	34.0* 42.0*	68.0 --	27.5* 47.5	63.0 47.5	25.0* 29.0*	29.0* 30.0*	28.5* 53.5	37.0* 61.0	47.5 47.5
Bend Tests Face, Root & Side	180°OK**	180°OK	180°OK	180°OK	180°OK	180°OK	180°OK	180°OK	180°OK
CVN Impact Values (ft-lb @ -4°F)	33 34 45 37Avg.	8 10 26 26Avg.	15 26 34 25Avg.	35 15 52 34Avg.	47 39 40 42Avg.	37 44 31 37Avg.	39 54 46 46Avg.	38 34 27 33Avg.	26 44 51 40Avg.

* Porosity
** Root Bend Failed at 80°

TABLE 9 - Results of Tests on Fillet Welds
1/2" and 1" Plates for Tensile and CVN Tests Respectively
(All Weld Metal Tests: Tensile .125" Diameter and CVN 1/2 Size 0.197" x 0.394")

Code	C1	L8	C4	H4	K4	L4	M4	R4	W4
Electrode	E6011	E7028	E7024	E7024	E7024	E7024	E7024	E7024	E7024
Tensile Strength (psi)	103,658	71,544	75,605	75,203	71,544	74,796	70,235	73,983	68,699
	68,699	59,756*	78,048	73,170	71,138	78,536	64,634	74,390	70,731
	73,170	73,170	78,048	73,170	68,292	76,422	70,731	72,357	68,699
	73,577	71,544	80,487	72,764	68,699	73,577	67,073	72,764	66,666
*Flaws									
Elong. % (in 1/2")	26.0	34.0	18.0	25.0	28.0	28.0	24.0	30.0	20.0
	30.0	8.0*	20.0	22.0	28.0	24.0	20.0	28.0	24.0
	26.0	28.0	28.0	18.0	27.0	25.0	28.0	22.0	22.0
*Flaws	27.0	32.0	24.0	28.0	14.0*	20.0	25.0	24.0	25.0
CVN Impact Tests (ft-lbs @ -4F)	13	15	8	11	11	10	3	8	8
	35	14	8	10	9	10	4	9	9
	17	12	11	10	9	8	12	10	10
Avg. X									
CVN Impact Tests (ft-lbs @ 32F)	30	14	10	11	10	8	10	11	7
	15	18	11	12	11	10	11	15	7
	20	20	9	16	12	10	16	16	9
Average									
Avg. X 3/2	32.4	25.9							

TABLE 10 - E7024 In-House Test Data

Manufacturer	Brand Code	Approval	Current	Size	Yield (ksi)	Tensile (ksi)	Elong. (%)	CVN Results	Chemical Analysis (Deposit) C	Mn	P	S	Si	Cr	Ni	Mo	V
A	A-1	ABS 2	AC	5/32	68.3	80.5	26	50ft-lb/32°F	.045	.76	.022	.022	.89	.05	.035	.021	.018
	A-1	ABS 2	AC	1/4	66.5	78.1	28	43ft-lb/32°F	.064	.76	.023	.023	.24	.026	.026	.012	.02
	A-2	A5.1-69	AC	3/16	68.5	77.5	26		-	.75			.25	.029	.035	.01	.035
	A-2	A5.1-69	DC	3/16	75.3	79.6	26		-	.75			.25	.029	.035	.01	.033
	A-2	A5.1-69	AC	1/4	69.0	75.5	28			.70			.23	.028	.045	.01	.032
	A-2	A5.1-69	DC	1/4	72.2	78.2	32		.09	1.38	.02	.014	.22	.029	.02	.01	.018
	A-3	A5.1-64T	AC	1/4	70.3	79.6	32		.082	1.33	.021	.015	.17	.035	.023	.01	.018
	A-3	A5.1-64T	DC	1/4	65.2	76.4	26										
B	B-1	ABS 2Y	AC	5/32	75.0	87.0	26	22ft-lb/-4°F	-	-	-	-	-	-	-	-	-
	B-1	ABS 2Y	AC	1/4	66.4	76.0	22	35ft-lb/-4°F	-	.65	-	-	.19	.04	.05	.01	.02
C	C-1	A5.1-69	AC	1/4	69.5	88.0	24	50ft-lb/68°F	.084	.76	.018	.01	.61	.05	.05	.05	.05
	C-1	ABS 1	AC	1/4	69.5	80.0	25	42ft-lb/68°F	-	-	-	-	-	-	-	-	-
D	D-1	A5.1-64T	DC	5/32	77.9	84.8	26	-	-	.94	-	-	.79	.097	.01	.01	.018
	D-1	A5.1-64T	DC	3/16	76.4	82.8	27	-	-	-	-	-	-	-	-	-	-
	D-1	A5.1-64T	DC	1/4	74.7	81.2	21	-	-	1.12	-	-	.57	.065	.01	.01	.014
E	E-1	A5.1-64T	AC	5/32	-	-	-	-	.082	.92	-	-	.58	.02	.05	.01	.01
	E-1	A5.1-64T	DC	5/32	-	-	-	-	.084	.92	-	-	.60	.03	.05	.01	.01
	E-1	A5.1-64T	AC	1/4	-	-	-	-	.078	.83	-	-	.61	.03	.01	.01	.01
	E-1	A5.1-64T	DC	1/4	-	-	-	-	.079	.85	-	-	.64	.04	.02	.01	.01
F	F-1	A5.1-69	AC	5/32	76.0	84.0	29										
	F-1	A5.1-69	DC(R)	5/32	74.0	85.0	27										
	F-1	A5.1-69	AC	3/16	76.0	84.0	22										
	F-1	A5.1-69	DC	3/16	74.0	82.0	23										
	F-1	A5.1-69	DC(R)	3/16	73.0	83.0	27										
	F-1	A5.1-69	AC	1/4	68.0	79.0	17										
	F-1	A5.1-69	DC	1/4	68.0	77.0	18										
	F-1	A5.1-69	DC(R)	1/4	70.0	79.0	17										

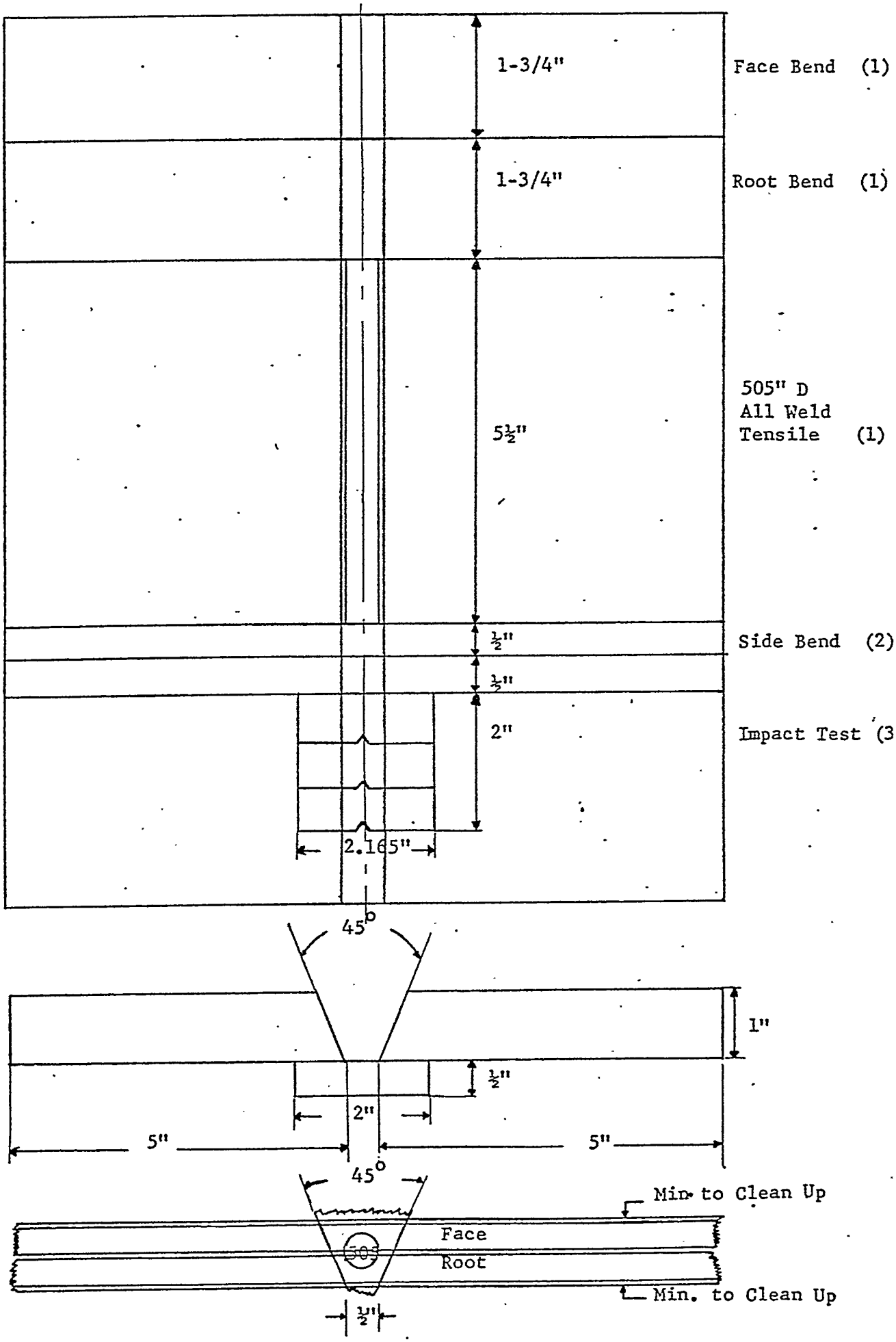
TABLE 10 - E7024 In-House Test Data (Continued)

Manufacturer	Brand Code	Approval	Current	Size	Yield (ksi)	Tensile (ksi)	Elong. (%)	CVN Results	Chemical Analysis (Deposit) C	Mn	P	S	Si	Cr	Ni	Mo	V
G	G-1	ABS 3	AC	4mm	70.7	74.8	27	41ft-lb/-20C	-	-	-	-	-	-	-	-	-
	G-1	ABS 3	AC	6mm	67.0	72.4	26	48ft-lb/-20C	-	-	-	-	-	-	-	-	-
	G-1	ABS 3	AC	4mm	71.8	75.5	28	51ft-lb/-20C	-	-	-	-	-	-	-	-	-
	G-1	ABS 3	AC	6mm	62.4	70.8	29	55ft-lb/-20C	-	-	-	-	-	-	-	-	-
H	H-1	ABS 2	AC	5/32	72.0	84.0	27	47ft-lb/0C	.1	.66	.009	.024	.31	-	-	-	-
	H-1	ABS 2	AC	3/16	74.0	86.0	27	42ft-lb/0C	-	-	-	-	-	-	-	-	-
	H-1	ABS 2	AC	5/32	68.8	78.6	18	66ft-lb/0C	-	-	-	-	-	-	-	-	-
	H-1	ABS 2	AC	1/4	68.4	80.0	22	80ft-lb/0C	.1	.66	.009	.024	.31	-	-	-	-
		treated	16 hrs.	250C	28,	24%		-	-	-	-	-	-	-	-	-	-
	H-3	ABS 2	AC	5/32	64.4	78.0	30	44ft-lb/0C	-	-	-	-	-	-	-	-	-
	H-3	ABS 2	AC	3/16	64.4	77.6	27	60ft-lb/0C	-	-	-	-	-	-	-	-	-
	H-3	ABS 2	AC	5mm	63.2	74.6	28	56ft-lb/0C	.06	.04	.022	.018	.34	-	-	-	-
	H-3	ABS 2	AC	5mm	63.2	74.8	27	62ft-lb/0C	-	-	-	-	-	-	-	-	-
I	I-1	ABS 1	AC	5/32	78.8	86.0	26	54ft-lb/20C	-	-	-	-	-	-	-	-	-
	I-1	ABS 1	AC	1/4	59.5	71.0	27	75ft-lb/20C	-	-	-	-	-	-	-	-	-
J	J-1	ABS 2	AC	5/32	79.2	86.9	25	34ft-lb/-10C	-	-	-	-	-	-	-	-	-
	J-1	ABS 2	AC	5/32	-	-	-	37ft-lb/0C	-	-	-	-	-	-	-	-	-
K	K-1	ABS 2	AC	4mm	69.4	80.6	22	45ft-lb/0C	-	-	-	-	-	-	-	-	-
	K-1	ABS 2	AC	6mm	71.7	80.6	20	42ft-lb/0C	-	-	-	-	-	-	-	-	-
L	L-1	A5.1-69	AC	4mm	67.3	74.9	32	70ft-lb/0C	-	-	-	-	-	-	-	-	-
	L-1	A5.1-69	AC	5mm	66.3	77.0	33	103ft-lb/0C	-	-	-	-	-	-	-	-	-
M	M-1	2, 1Y*	AC	4mm	72.1	81.2	27	62ft-lb/0C	.089	.79	.023	.011	.43	-	-	-	-
	M-1	2, 1Y*	AC	6mm	69.5	79.2	27	50ft-lb/0C	.084	.70	.018	.012	.46	-	-	-	-
N	N-1	A5.1-69	AC	6mm	71.0	81.0	22	-	-	-	-	-	-	-	-	-	-
	N-1	A5.1-69	AC	6mm	71.0	84.0	22	-	-	-	-	-	-	-	-	-	-

TABLE 10 - E7024 In-House Test Data (Continued)

Manufacturer	Brand Code	Approval	Current	Size	Yield (ksi)	Tensile (ksi)	Elong. (%)	CVN Results	Chemical Analysis (Deposit) C	Mn	P	S	Si	Cr	Ni	Mo	V
O	O-1	ABS 2	AC	4mm	71.0	81.0	25	42ft-lb/0C	-	-	-	-	-	-	-	-	-
	O-1	ABS 2	AC	6.5mm	71.0	77.0	23	49ft-lb/0C	-	-	-	-	-	-	-	-	-
P	P-1	ABS 2	AC	4mm	68.0	80.0	26	58ft-lb/0C	-	-	-	-	-	-	-	-	-
	P-1	ABS 2	AC	4mm	67.5	79.9	23	-	-	-	-	-	-	-	-	-	-
	P-1	ABS 2	AC	5mm	64.8	77.5	26	58ft-lb/0C	-	-	-	-	-	-	-	-	-
	P-1	ABS 2	AC	5mm	63.8	76.7	22	-	-	-	-	-	-	-	-	-	-
Q	Q-1	ABS 2		4mm	66.1	76.0	28	41ft-lb/0C	.05	.68	.016	.017	.43	-	-	-	-
	Q-1	ABS 2		5mm	65.1	73.4	26	38ft-lb/0C	.05	.66	.016	.014	.39	-	-	-	-
R	R-1	A5.1-69	AC	4mm	71.0	83.0	27	-	-	.60	-	-	.30	.05	.01	.01	.01
	R-1	A5.1-69	AC	5mm	65.7	78.8	19	-	-	-	-	-	-	-	-	-	-
	R-1	A5.1-69	AC	6mm	63.2	75.3	25	-	-	.64	-	-	.33	.06	.01	.01	.01
	R-1	A5.1-69	DC(S)	4mm	65.1	81.2	30	-	-	.72	-	-	.36	.08	.04	.01	.04
	R-1	A5.1-69	DC(S)	5mm	68.3	80.0	29	-	-	-	-	-	-	-	-	-	-
	R-1	A5.1-69	DC(S)	6mm	64.8	77.6	27	-	-	.95	-	-	.50	.01	.02	.01	.03

* Values converted from Kg/mm^2 and N/mm^2 to ksi were rounded off to nearest 0.1.


1-3/4"
Face Bend (1)
1-3/4"
Root Bend (1)
5½"
505" D
All Weld
Tensile (1)
½"
Side Bend (2)
½"
2"
Impact Test (3
2.165"
45°
1"
½"
2"
5"
5"
45°
Min. to Clean Up
Face
Root
Min. to Clean Up
½"

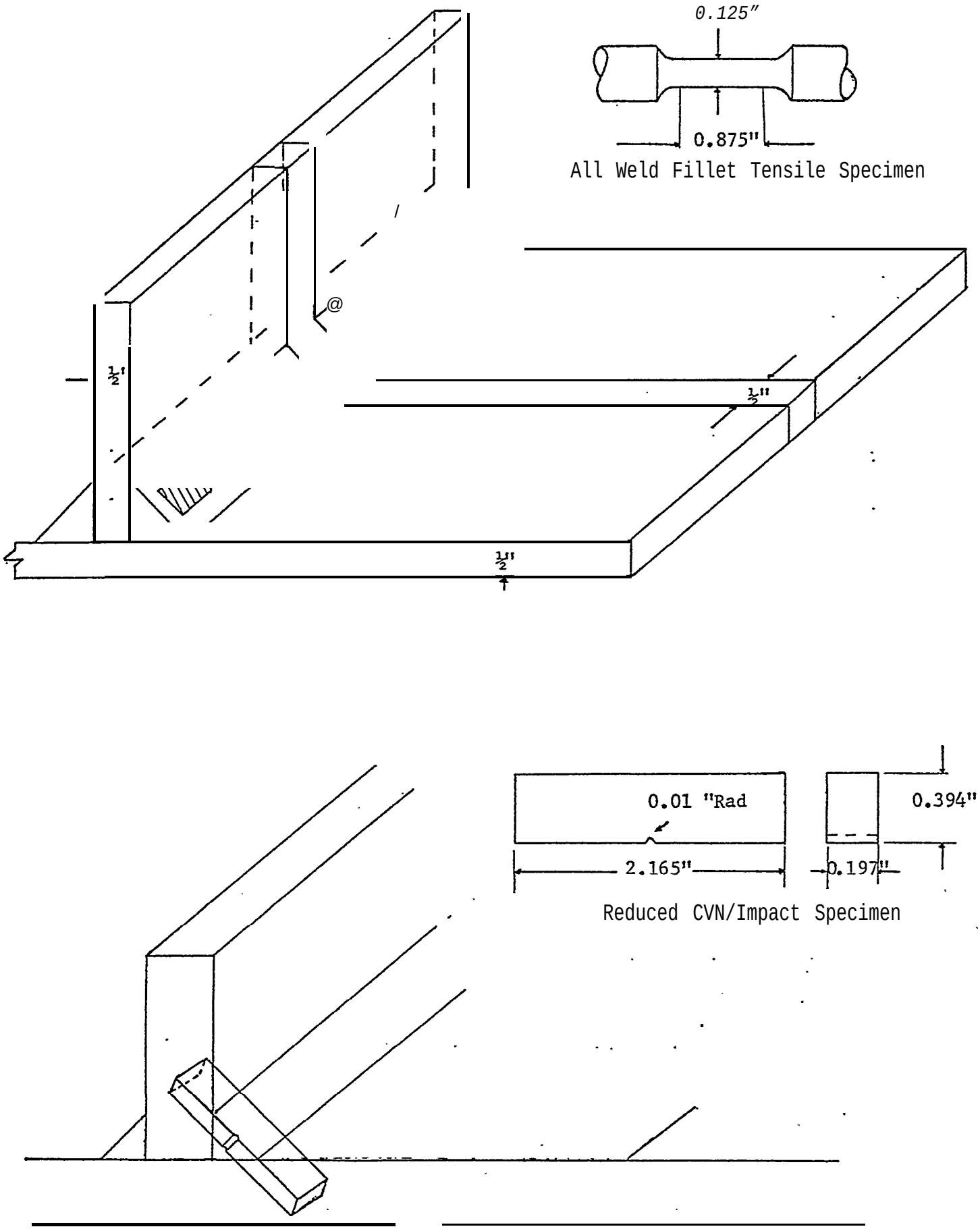


Figure 2. Fillet Weld Test Assembly

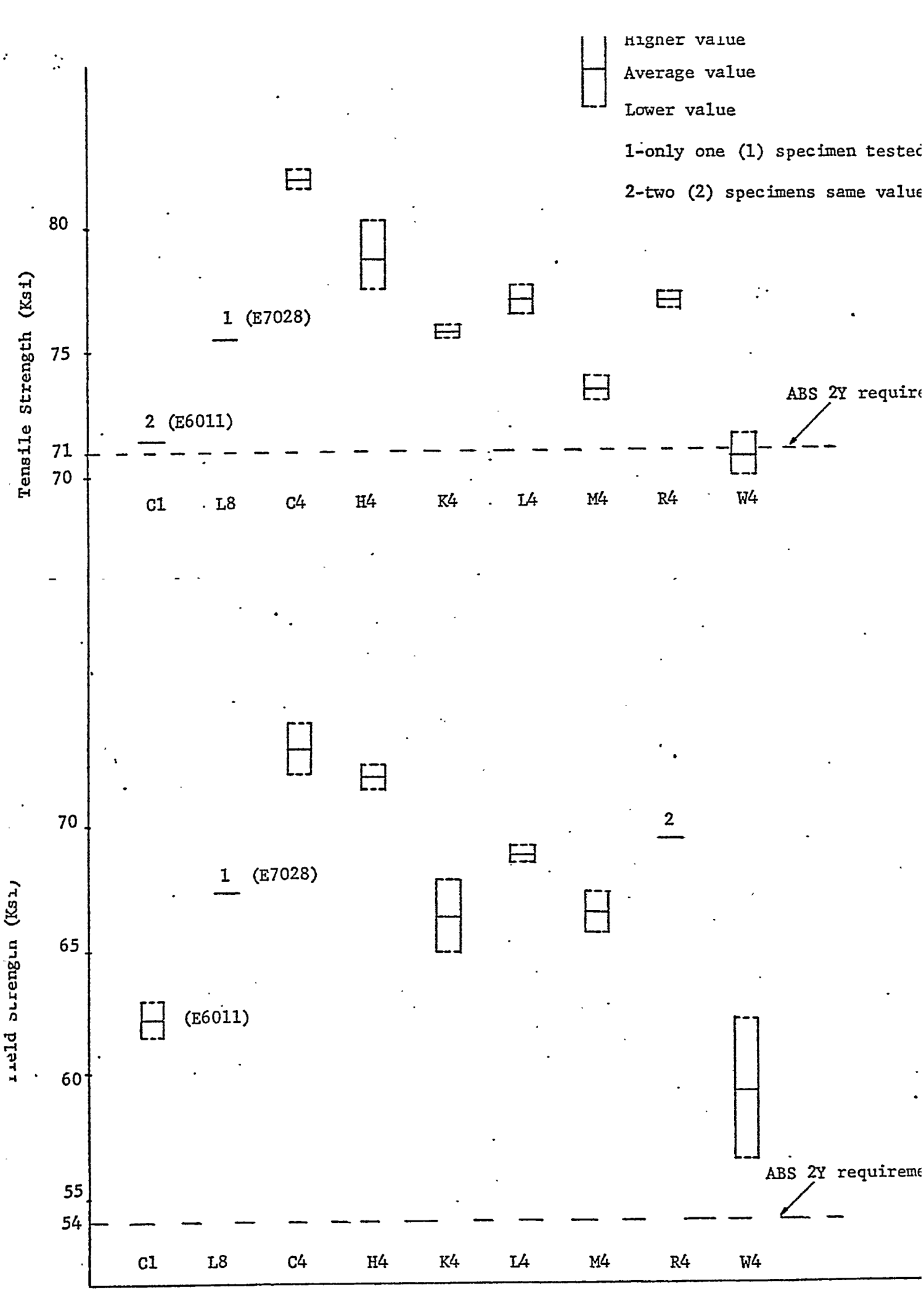


Fig. 3a E7024 Electrodes

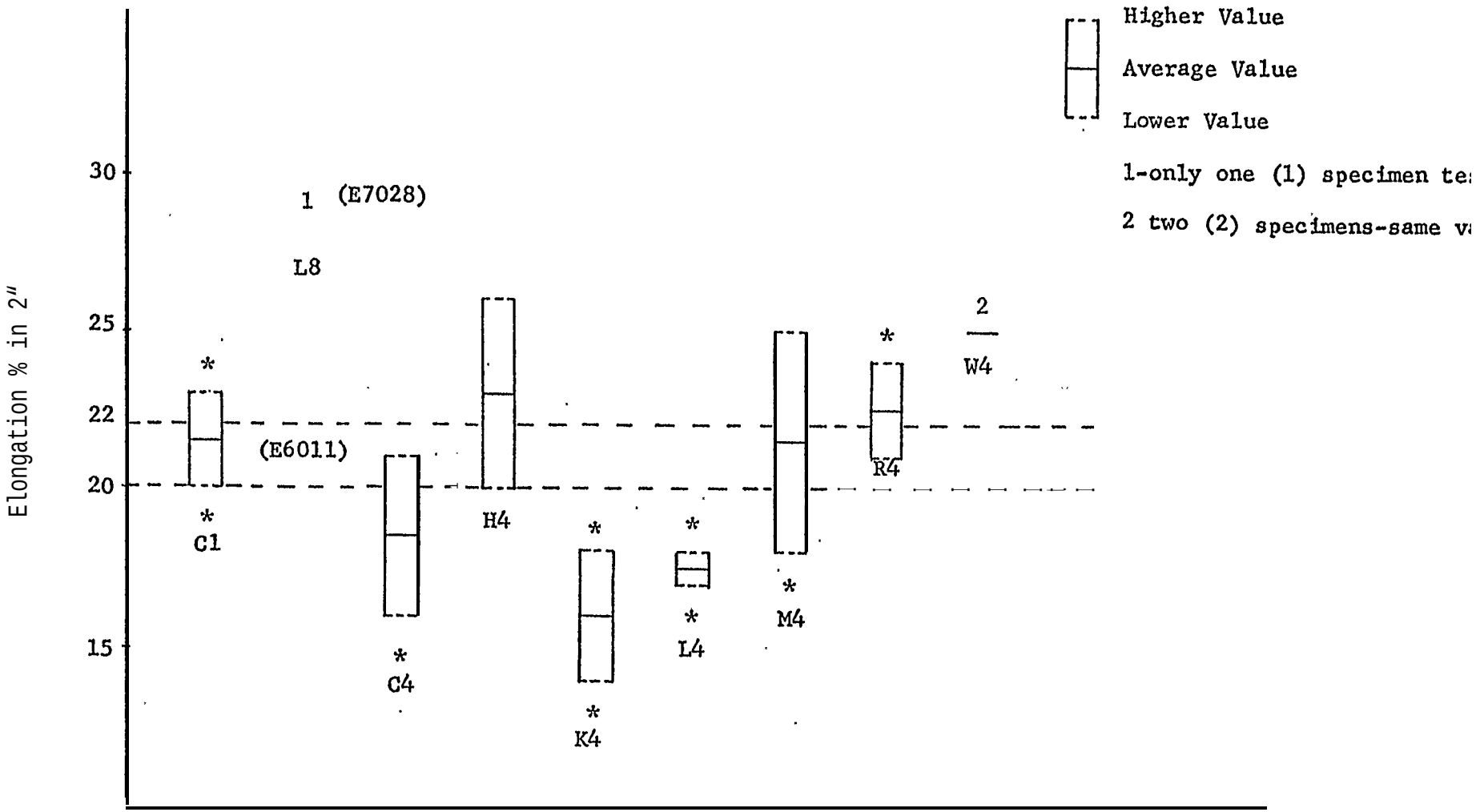
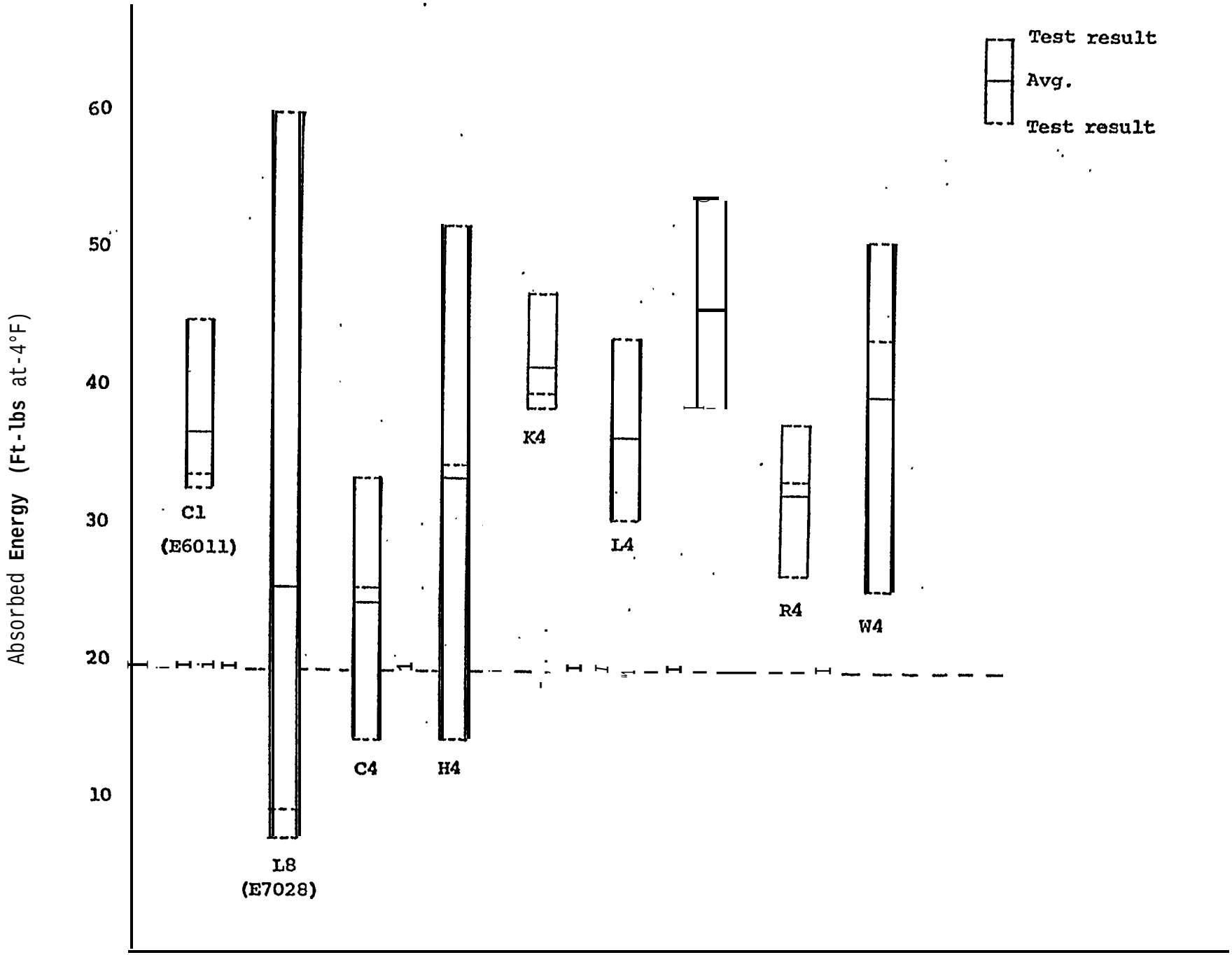


Fig 3b E7024 Electrodes



E7024 Electrodes

Fig. 4 Butt Welds Charpy V-notch Impact Test Results

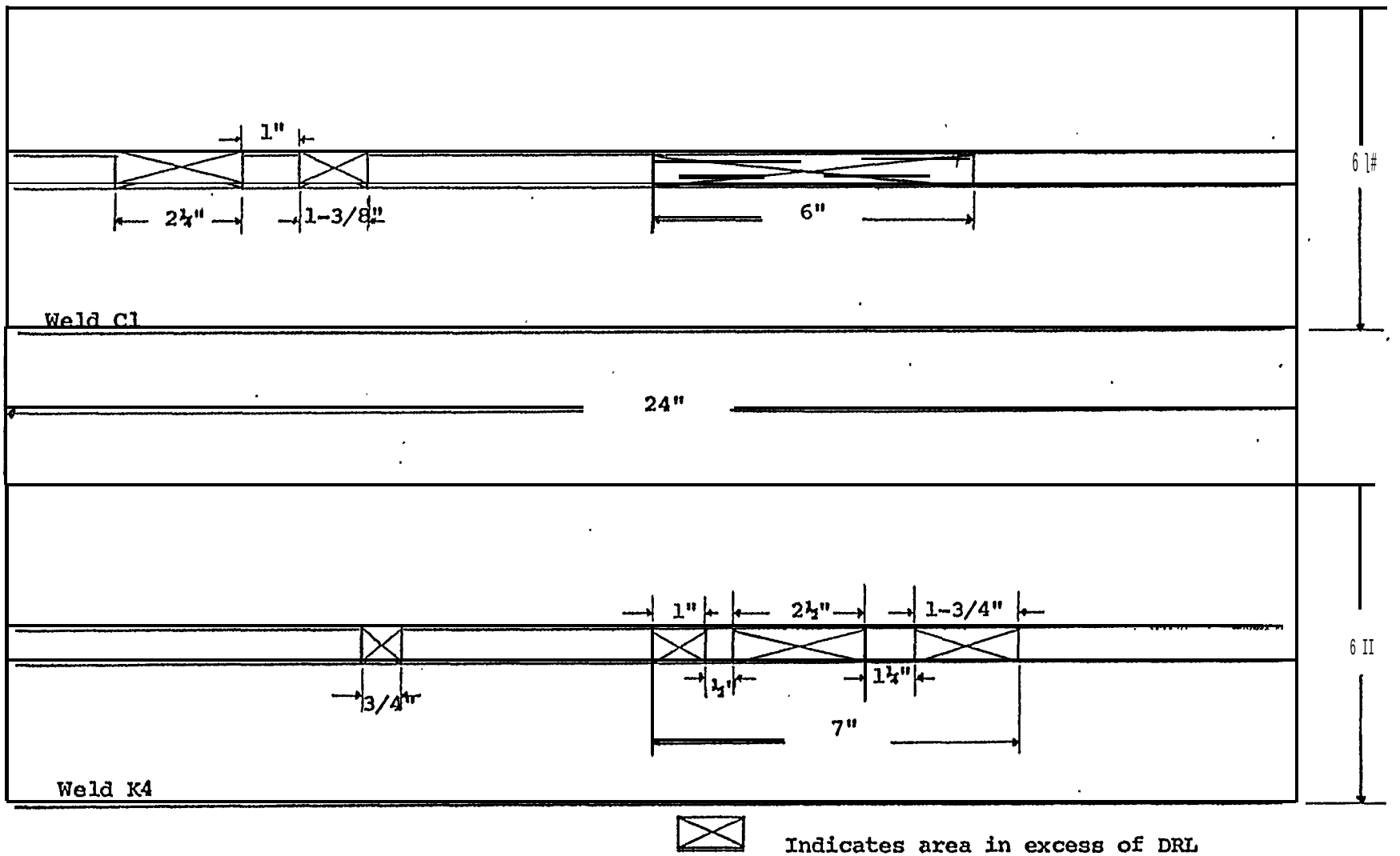
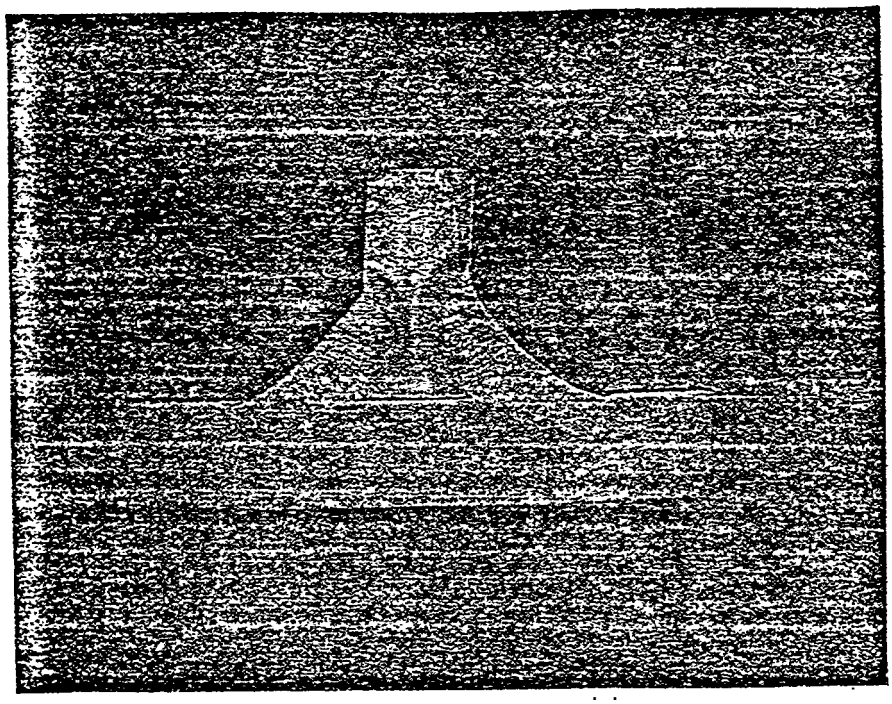
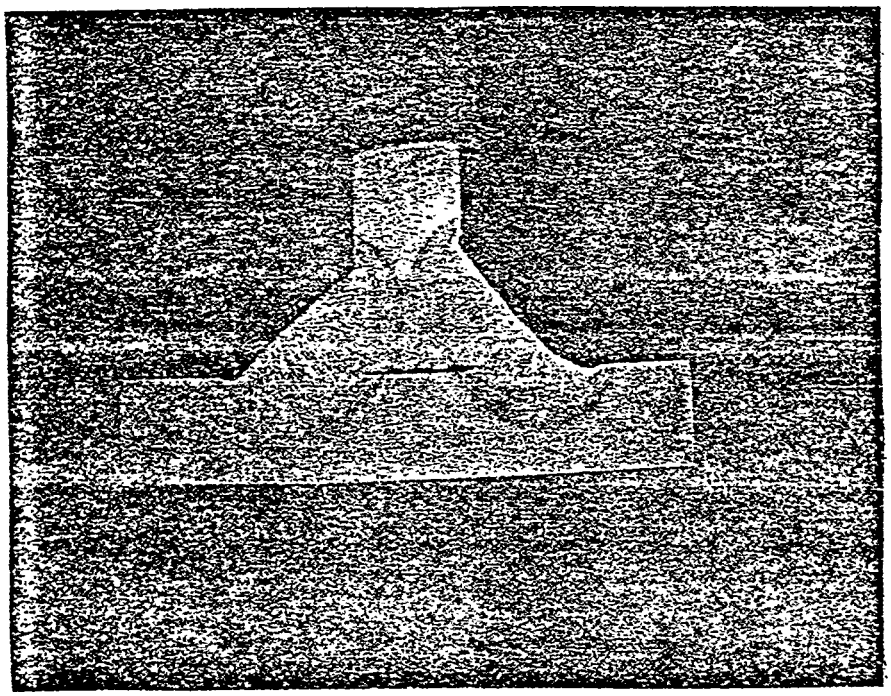


Fig. 5 Significant Ultrasonic Indications-Welds C1,K4

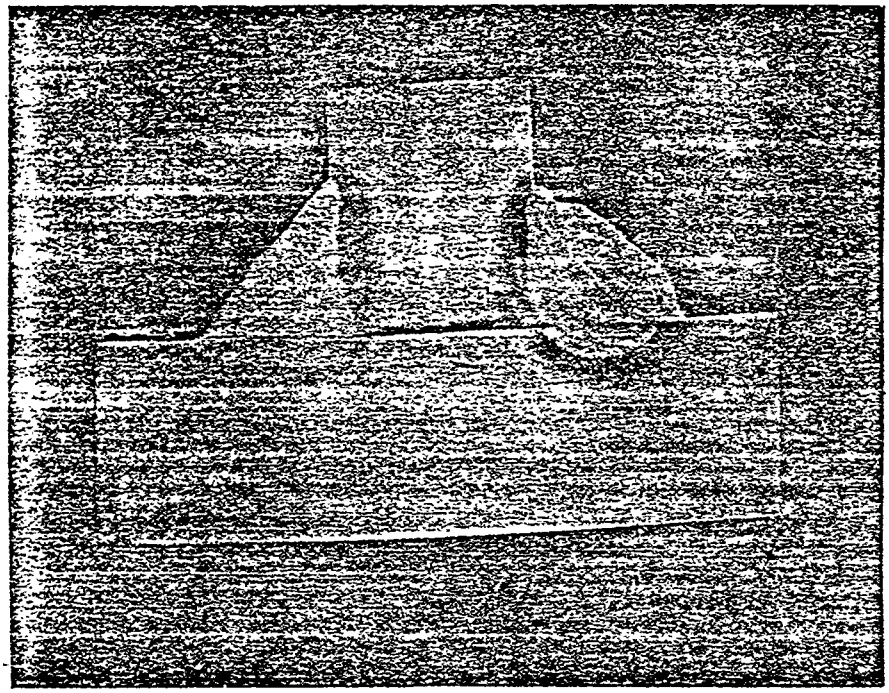


Weld R-4

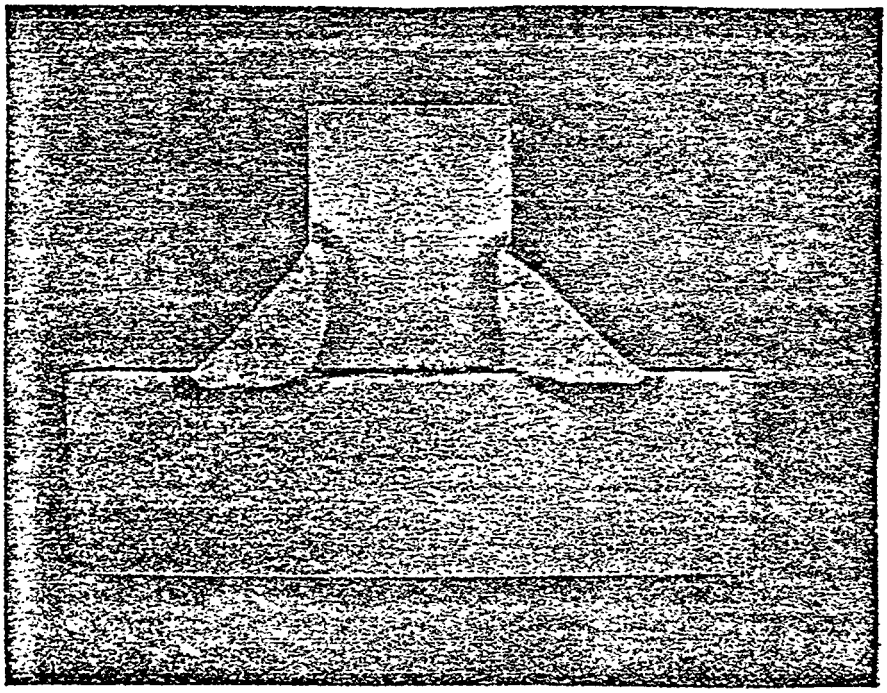


Weld W-4

Fig 6a Macro Sections of Fillet Welds



Weld C-1



Weld L-8

Fig 6b Macro Sections of Fillet Welds

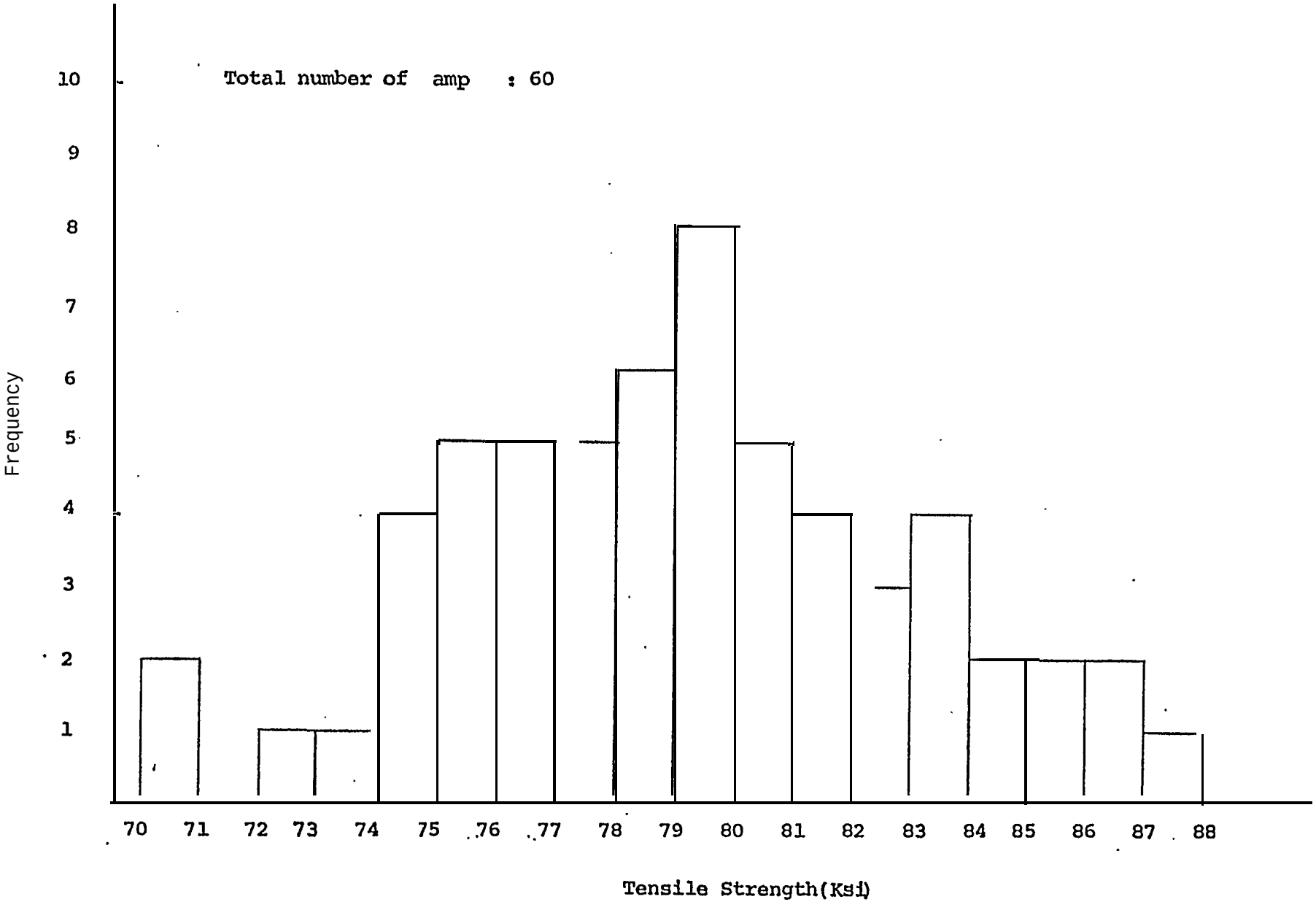


Fig. 7 E7024 Tensile Strength Test Results (In-house data)

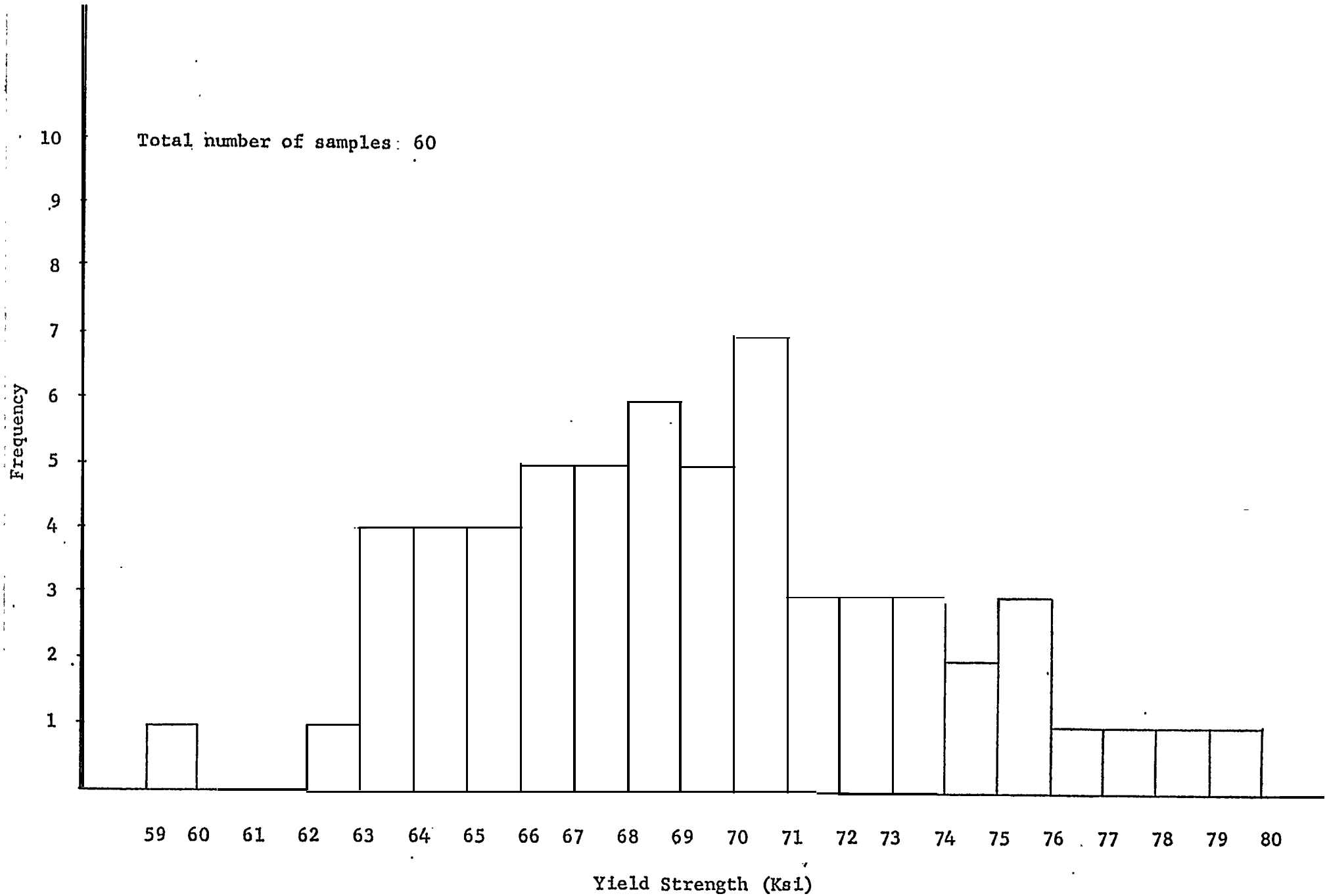
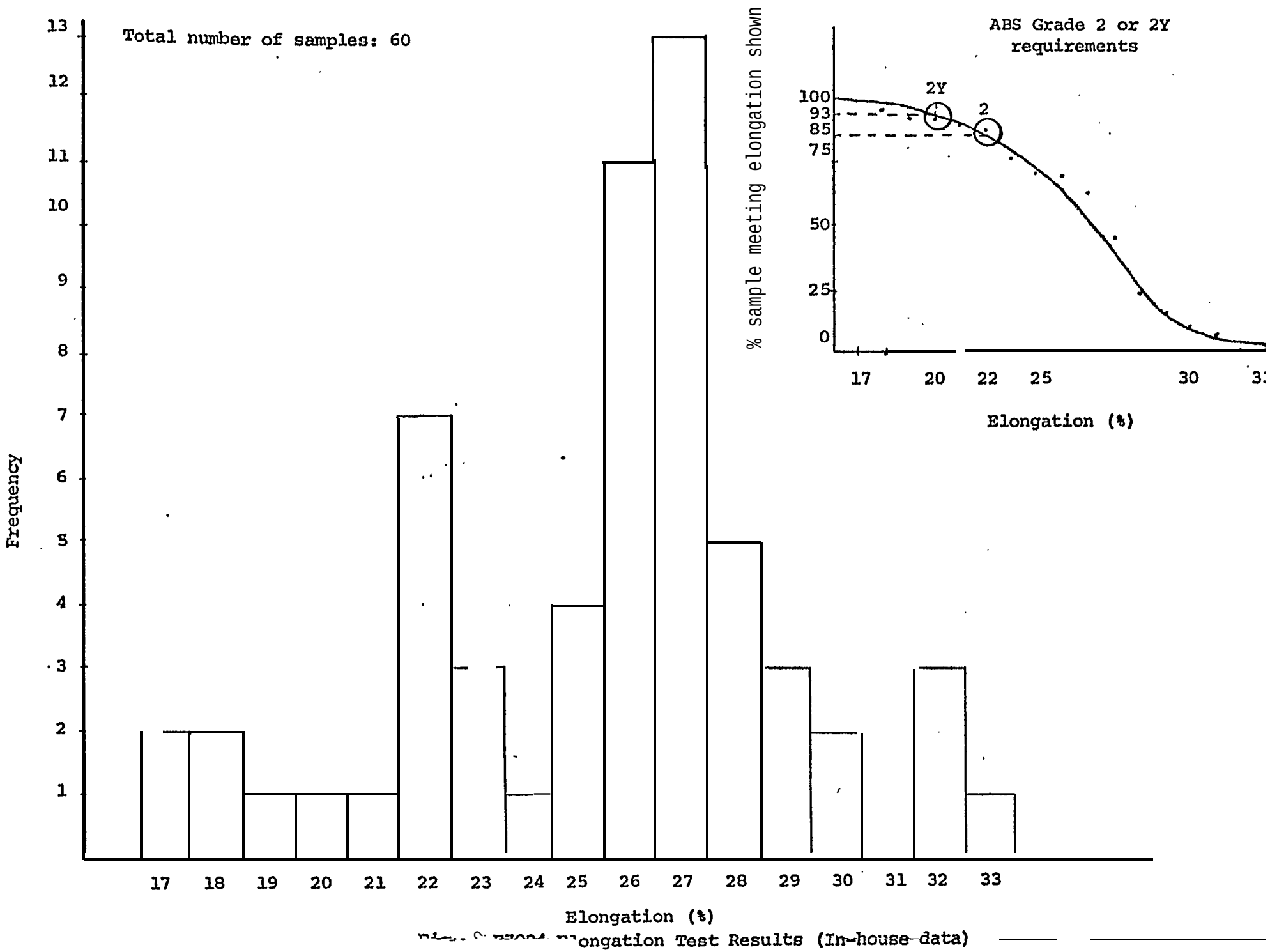


Fig. 8 E7024 Yield Strength Test Results (In-house data)



ongation Test Results (In-house data)

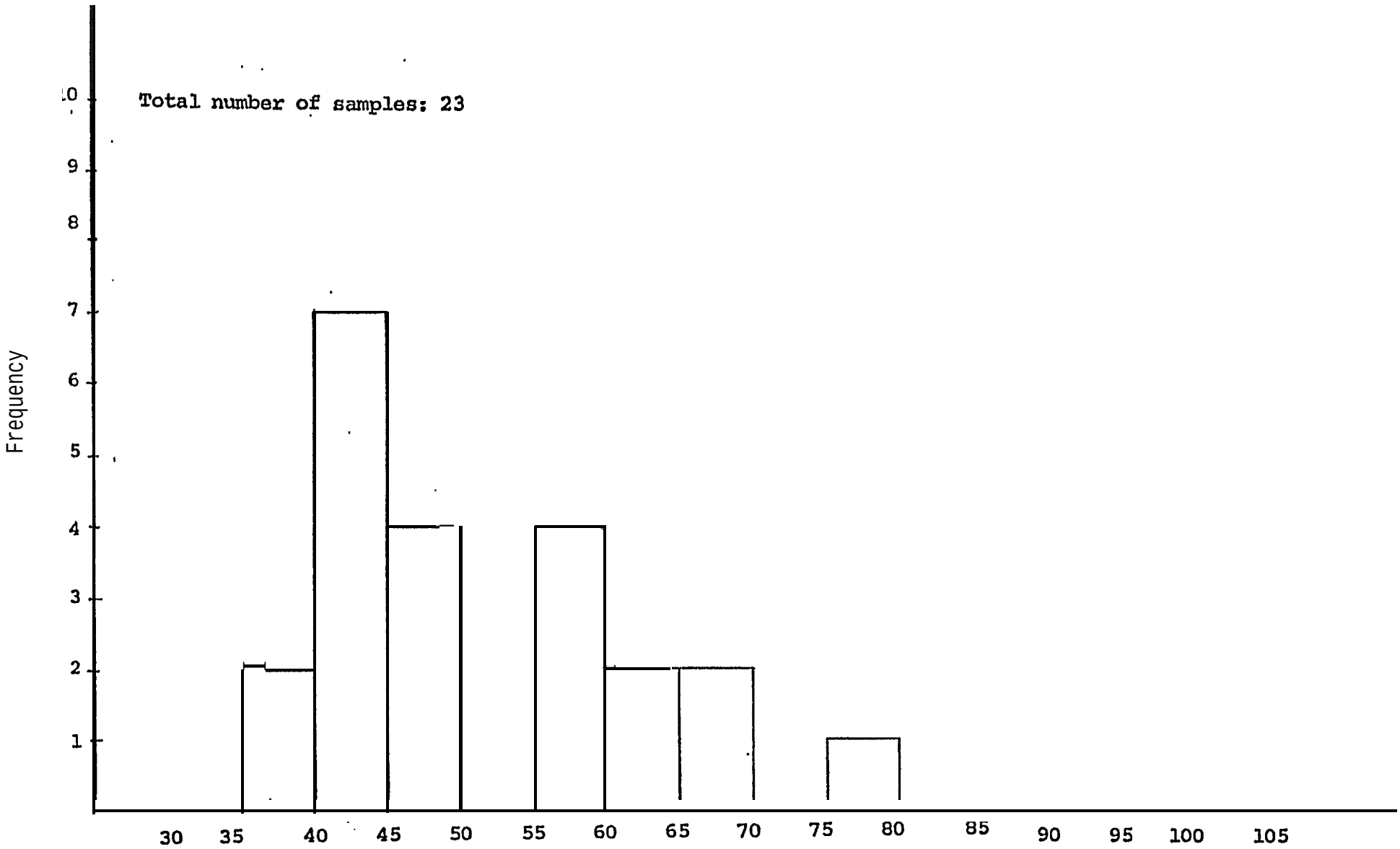


Fig. 10 E7024 CVN Test Results (In-house Data)